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THE EFFECT OF BEDREST ON VARIOUS PARAMETERS OF PHYSIOLOGICAL FUNCTION

PART XI. THE EFFECT OF BEDREST ON BLOOD VOLUME, URINARY VOLUME, AND URINARY ELECTROLYTE EXCRETION

by F. B. Vogt, W. A. Spencer, D. Cardus, and C. Vallbona

Prepared under Contract No. NAS 9-1461 *by*
TEXAS INSTITUTE FOR REHABILITATION AND RESEARCH
Houston, Texas
for

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ABSTRACT

Seven subjects participated in 14-day bedrest studies using controlled diets and careful measurement of intake and output. A 14-day bedrest period was followed by a 14-day recovery period, which in turn was followed by a second 14-day bedrest period to which was added an exercise program. A diuresis and naturesis was observed with bedrest. Day to day variation in plasma volume determination makes interpretation of this measurement difficult.

FOREWORD

This study is a part of a NASA investigation of the effect of bedrest on various parameters of physiological function. It was sponsored by NASA Manned Spacecraft Center under Contract NAS-9-1461, with Dr. Lawrence F. Dietlein, Chief, Space Medicine Branch serving as Technical Monitor.

This study was conducted in the Immobilization Study Unit of the Texas Institute for Rehabilitation and Research, the Texas Medical Center. The authors are affiliated with Baylor University College of Medicine as follows: Dr. Vogt, Department of Rehabilitation; Dr. Spencer, Department of Rehabilitation; Dr. Cardus, Departments of Rehabilitation and Physiology; and Dr. Vallbona, Departments of Rehabilitation, Physiology, and Pediatrics.

The authors wish to acknowledge the assistance of Mrs. Patsy Dominy and Mrs. Carolyn Caldwell in the typing of this manuscript; Miss Mary Walters and Mr. Troy Allen in the preparation of the report; Dr. Philip Hudgins, W.G. McTaggart and Anna Maxwell in performing the blood volume measurements; and of Judy Brock, Ann Landry, and Albert Canida in performing the biochemical analyses.

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SUMMARY

An experimental study was performed at the Texas Institute for Rehabilitation and Research in the Summer of 1963 to evaluate the effect of periodic isometric exercises in preventing the cardiovascular deconditioning of bedrest. Seven healthy young adult males participated in the study which was divided into two 14-day periods of bedrest, preceded and followed by an observation period. The first bedrest period consisted of bedrest without treatment. During the second bedrest period, a program of isometric exercise was added in which the subject developed a thrust force between his shoulder and feet. The subjects ate a controlled diet approximating 2200 calories, with a salt content of approximately 9 grams, and were allowed to drink fluid ad libitum. Intake and output were measured carefully and radio-iodinated serum albumin (RISA) plasma volume determinations were made throughout the study.

A diuresis was noted with bedrest, as well as a naturesis and an increased excretion of potassium. The observations did not allow incrimination of the specific factor responsible for their change. A large variation in day-to-day plasma volume determinations made interpretation of this measurement difficult.

INTRODUCTION

Observations of orthostatic cardiovascular instability and dehydration have been made in association with two relatively short duration orbital flights of the United States[1,2] to date. Water immersion[3,4,5,6,7,8,9] and bedrest[10,11,12,13] experiments are believed to simulate some of the conditions of space flight. Information from such studies may be helpful to predict changes which can occur in association with space flight and for interpretation of some of the observations made in association with an actual space flight.

This paper reports on observations of RISA blood volume, urinary volume, and urinary electrolyte excretion made on healthy subjects during a 14-day bedrest study. The experimental design provided for two bedrest immobilization study periods of 14-days duration using the same group of six subjects. The purpose of the first period was to collect data that would be representative of the changes in the above measurements in the individual subjects as a result of bedrest. The second bedrest period was identical to the first, except for the addition of periodic isometric exercises. Comparison of the data obtained during bedrest to that obtained during bedrest with exercise should thus provide information on the effect of adding the exercise.

METHOD

A. Subjects

Six healthy adult males whose ages ranged from 21 to 34 years were used in each bedrest period. Five of the subjects participated in both the bedrest and bedrest with exercise periods. Subject T. O. participated in only the bedrest period and was replaced by subject A.I. in the bedrest with exercise period. The subjects were selected and considered for use in the study on the basis of their availability and of their interest to participate in the study. The details of the experimental procedures were explained to them prior to selection. The subjects were then given a complete medical history and physical examination, which was followed by routine laboratory and X-ray tests. Table I gives the physical characteristics and occupations of the subjects participating in this study.

B. Experimental Conditions

Figure 1 shows a calendar of the periods of the study. The subjects were admitted to the Texas Institute for Rehabilitation and Research 1 week prior to the start of bedrest. Special tests were performed during this time and data were obtained to represent the pre-bedrest baseline condition of the subject. During this period the subjects ate the experimental diet and slept in the immobilization study ward. Prior to and immediately after the 14-day bedrest immobilization periods, tilt table studies were performed to measure orthostatic changes that occur with tilting of the subjects.

The subjects were kept at strict bedrest during the 14-day immobilization period. They were allowed to turn over in bed, and were given one pillow for use under the head. They were allowed to read in bed and feed themselves. They were not allowed to sit in bed, raise their arms and legs above head level, or get up for bathroom privileges. They were fed 2200-2500 calorie low-residue diets with an approximate salt content of 8.5 to 9.0 grams of sodium chloride. During the study, they were allowed to drink distilled water ad libitum, but the intake was recorded carefully.

TABLE I

PHYSICAL CHARACTERISTICS AND OCCUPATIONS OF SUBJECTS PARTICIPATING IN FOURTEEN-DAY STUDY

Patient		Age (Years)	Height (Cm.)	Weight (Kg.)	Body Surface Area (m^2)	Usual Occupation
TIRR No.	Name					
70-0-11	A. L.	33	170.3	62.7	1.73	Student (athlete)
70-0-12	T. O.	21	188.0	79.2	2.06	Student
70-0-13	M.O.	24	177.8	79.2	1.97	Student (athlete)
70-0-14	D.C.	24	180.4	75.0	1.94	Student
70-0-16	C.B.	24	185.5	85.7	2.10	Student counselor
70-0-17	C.P.	34	180.4	77.0	1.97	School teacher
70-0-18	A.I.	22	165.0	50.0	1.54	Student (athlete)

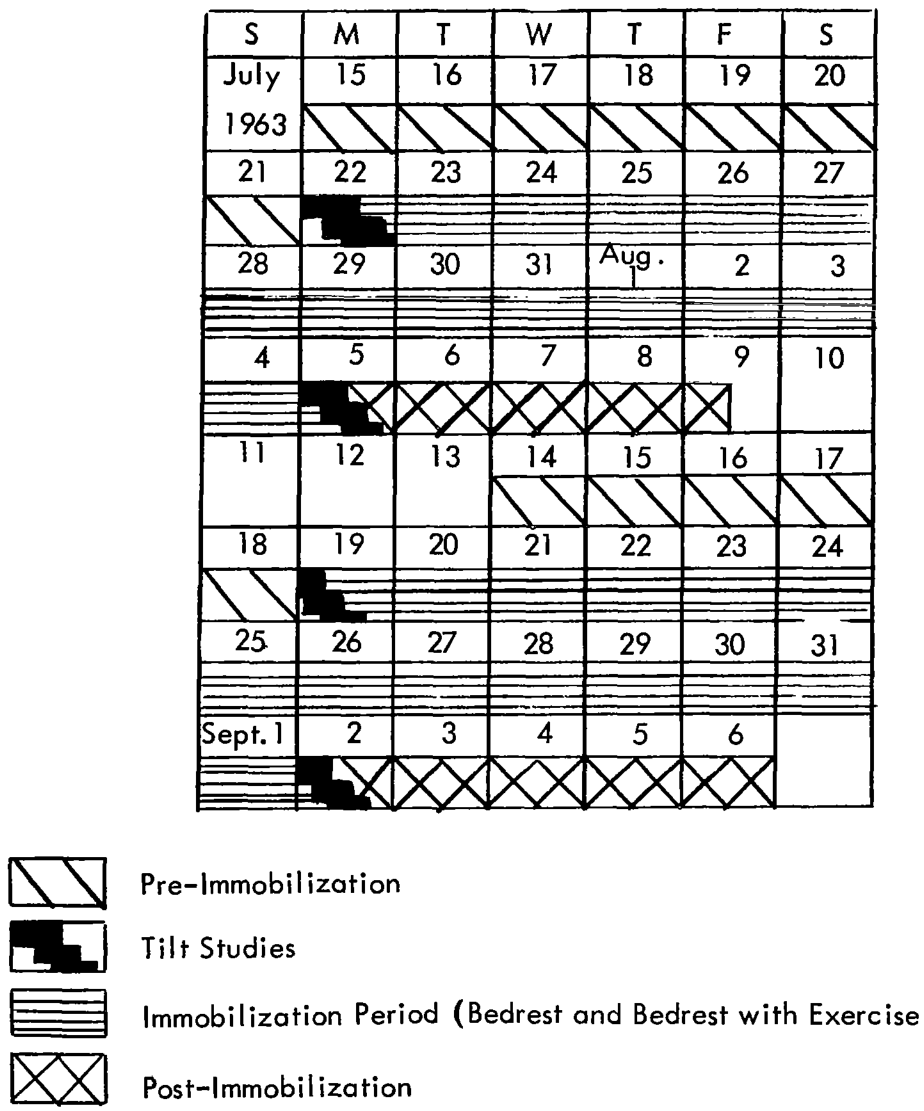

Figure 1. Periods of study.

During the second immobilization period, the subjects were required to perform isometric exercises six times daily. The exercise procedure was designed for performance in bed on a specially developed thrust rack and consisted of development of a thrust force between the heels and shoulders of the subject. For each of the six exercise periods, the subjects performed exercise efforts of 5 seconds duration with 5 seconds of rest between efforts in the following manner: (a) 10 controlled efforts with knees partially flexed, (b) 5 controlled efforts with knees in extension, and (c) 2 maximal efforts with knees partially flexed. The subjects were required to attain a thrust force determined prior to the bed-rest period to be approximately 300 pounds and which represented approximately 60 percent of maximal effort. The amount of force exerted with each effort was measured and recorded, and in addition was presented to the subject on a meter to allow him to duplicate a prescribed exercise load.

C. Urine Collection and Analysis

Urine was collected from each individual over 12-hour collection periods which ran from 7 a.m. to 7 p.m. and 7 p.m. to 7 a.m. The urine was collected in bottles immersed in ice; an aliquot of the 12-hour sample was refrigerated and analyzed at a later time.

On some occasions, a subject was unable to void at the prescribed time. The time at which he did void was recorded, and the urine volume was corrected to an "equivalent" 12-hour sample. For example, if the collection period was actually 13 hours, the urine volume was multiplied by a correction factor of 12/13 to obtain the equivalent 12-hour sample. The next collection period would likely be 11 hours, in which case the urine volume was multiplied by 12/11 to obtain the 12-hour equivalent volume. It is realized that the rate of excretion was not necessarily constant during the 12-hour collection period, but the above manipulation was thought justified in order to present results in a form which would allow comparison of findings on different subjects and of the same subject on different days.

Urine sodium and potassium were determined by the technique of Flame Photometry.

D. Blood Volume

Blood volume determinations were made using radio-iodinated serum albumin (RISA). On the days blood volumes were measured, determinations were made at approximately 8 a.m. After obtaining a control blood sample, five microcuries of RISA were injected into the subject's antecubital vein. The post injection blood sample was obtained 10 minutes later from the opposite antecubital vein. The whole blood sample then was counted in a well-counter and appropriate calculations were made to express the results as a RISA blood volume.

RESULTS

A. Urine Volume

The values for daily urine volumes on the six individuals are presented in Table II. Day 8 is the beginning of the first bedrest period and day 22 the end. Day 36 is the beginning of the bedrest with exercise period and a day 50 is the end. The equivalent volume for the two 12-hour periods was totaled to give a 24-hour representation. Figure 2 is a plot of the averaged daily urine volumes on all subjects. The results of creatinine measurements on each 12-hour urine sample support the reliability of the urine collecting procedure.

The average urine output was greater by approximately 350 cc. during the bedrest period compared to the average 24-hour urinary volume output prior to bedrest. The average 24-hour urine output was the same for the first week of bedrest as for the second week. Following the first bedrest period, the average urine volume dropped to approximately the pre-bedrest average. There was a diminished average daily fluid intake of approximately 550 cc., coincident to the increased average 24-hour urinary volume output of approximately 350 cc. in the first bedrest period, or a net average daily change of 900 cc. Measurements are not available to quantitate insensible water loss. However, it was noted that the subjects perspired very little during the first period of recumbency, but did show definite sweating during the second period of recumbency at the times they performed isometric exercises. During the second study period, to which exercises were added, the subjects showed an average increase in 24-hour urine volume of approximately 300 cc., and an average daily decrease in average fluid intake of approximately 200 cc., or a net average change of 500 cc. daily.

Inspection of the values of the volumes for the 12-hour collection periods showed there was a higher urinary volume output during the 7 a.m. and 7 p.m. collection period compared to the 7p.m. to 7a.m. period.

B. Urine Electrolytes

The values for the 24-hour urinary sodium and potassium excretion are presented in Tables III, parts I and II. The values for the two daily 12-hour equivalent sodium and potassium excretions were added to obtain 24-hour excretion values. Table IV presents the calculated ratio of sodium to potassium for corresponding time periods on the individual subjects. Figure 3 shows the average daily sodium and potassium values for the six subjects during the study. Figure 4 shows the sodium-potassium ratio on the individual subjects and Figure 5 shows the average daily sodium-potassium ratio on the six subjects .

Inspection of the data in these tables and figures reveals an increased sodium excretion upon assumption of the recumbent position. The sodium excretion then shows a downward trend as recumbency continues with an even smaller

Table II

TWENTY-FOUR HOUR URINE VOLUMES (ml.)

Fourteen Day Bedrest Experiment

A. Bedrest Period

Day	AL	TO	MO	DC	CB	CP	AI	Average
3	1120	1390	960	1375	---	---	---	1211
4	1290	1565	1190	1490	1120	---	---	1331
5	1230	1730	720	1200	750	1425	---	1176
6	1400	790	700	885	640	705	---	853
7	1360	925	710	830	900	780	---	918
8 *	733	1480	1310	1289	1318	1071	---	1200
9	1510	1552	1658	1486	1320	1903	---	1572
10	1280	1464	1630	1360	1150	1112	---	1333
11	1635	2192	1257	1085	1105	960	---	1372
12	1815	2350	1156	2457	1360	1130	---	1711
13	1565	2800	1064	895	1030	870	---	1371
14	1570	2800	1145	1870	1090	970	---	1574
15	1985	2980	1940	2615	1410	1720	---	2108
16	1430	1793	1263	1440	1130	960	---	1336
17	1500	2415	1327	1300	1070	910	---	1420
18	1760	1640	1310	2190	690	1270	---	1477
19	1485	1310	1031	1185	800	1310	---	1187
20	1320	1260	1274	1880	930	1115	---	1297
21	1425	1690	1061	1485	1225	1360	---	1374
22 **	1510	1605	1224	3300	889	1560	---	1681
23	795	1035	730	1150	750	550	---	835
24	1310	990	598	725	1200	640	---	911
25	1160	1270	628	790	1500	525	---	979
Average	1415	1697	1125	1490	1063	1088	---	1314

* First day of bedrest.
** Last day of bedrest.

Table II

TWENTY-FOUR HOUR URINE VOLUMES (ml.)

Fourteen Day Bedrest Experiments

B. Bedrest with Exercise Period

Day	AL	TO	MO	DC	CB	CP	AI	Average
32	1216	---	765	1110	1060	1500	---	1130
33	1150	---	880	665	1130	940	1470	1039
34	1270	---	682	1250	1295	790	1160	1075
35	1275	---	573	780	825	630	1400	914
36 *	2021	---	1543	2045	1355	1400	1460	1637
37	1365	---	1060	1245	1130	1215	1460	1245
38	1295	---	1064	1400	1005	890	1596	1208
39	1690	---	1177	3910	1110	1580	1980	1908
40	1220	---	1034	1050	840	1430	1280	1142
41	1520	---	1139	1680	1000	830	1280	1242
42	1650	---	1474	1510	1230	1760	1495	1520
43	1335	---	1222	870	930	1300	975	1105
44	1410	---	1180	1110	770	910	1170	1092
45	1350	---	1833	1200	1155	1560	1200	1383
46	1390	---	1017	1480	1355	1175	1090	1251
47	1280	---	1153	1795	1200	1030	930	1231
48	1225	---	1379	1660	1070	1220	1130	1281
49	1490	---	941	2025	---	1270	1065	1358
50 **	1620	---	706	810	---	875	995	1001
51	820	---	610	900	---	500	750	716
52	1415	---	570	790	---	625	1170	914
53	1160	---	308	715	---	600	900	737
Average	1371	---	1011	1364	1086	1092	1236	1198

* First day of bedrest.

** Last day of bedrest.

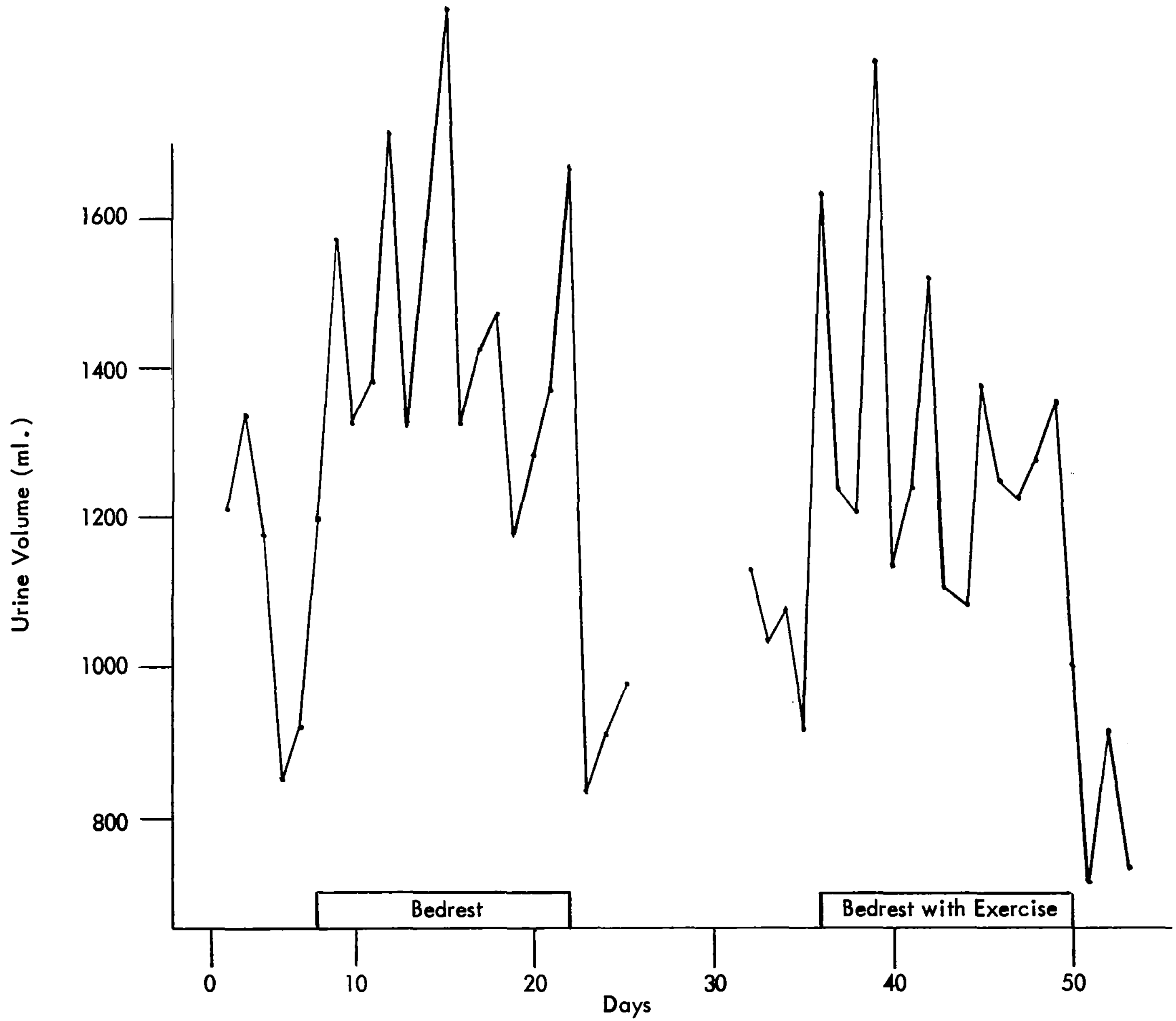

Figure 2. Average daily 24-hour urine volumes.

Table III - Part I

URINARY SODIUM (mEq)

Fourteen Day Bedrest Experiment

A. Bedrest Period

Day	AL	TO	MO	DC	CB	CP	AI	Average
3	152	196	197	219	---	---	---	191
4	205	294	251	290	312	---	---	270
5	114	201	121	174	157	158	---	154
6	161	106	116	206	130	131	---	142
7	273	156	116	174	206	179	---	184
8 *	156	196	291	232	326	261	---	244
9	325	317	382	245	362	330	---	327
10	264	232	191	245	269	223	---	237
11	239	274	296	246	272	228	---	259
12	300	329	261	277	319	199	---	281
13	260	156	190	177	181	182	---	191
14	257	207	205	248	208	226	---	225
15	248	335	258	328	239	310	---	286
16	218	178	190	214	169	128	---	183
17	237	263	288	254	232	179	---	242
18	203	217	197	225	119	206	---	195
19	169	178	150	192	157	155	---	167
20	198	151	133	184	180	140	---	164
21	207	188	179	199	241	162	---	196
22 **	190	157	81	111	132	133	---	134
23	93	104	107	114	106	89	---	102
24	171	114	80	116	237	105	---	137
25	192	114	106	178	233	102	---	154
Average	210	203	191	211	218	182	---	203

* First day of bedrest.

** Last day of bedrest.

Table III - Part I

URINARY SODIUM (mEq.)

Fourteen Day Bedrest Experiment

B. Bedrest with Exercise Period

Day	AL	TO	MO	DC	CB	CP	AI	Average
32	247	---	187	237	286	198	---	231
33	175	---	187	135	186	157	247	181
34	233	---	136	182	234	132	197	186
35	161	---	87	160	146	96	237	148
36 *	358	---	324	345	282	277	159	291
37	276	---	263	252	281	282	357	285
38	272	---	248	315	252	228	280	266
39	373	---	253	275	260	318	302	297
40	217	---	204	171	154	221	221	198
41	303	---	240	250	197	222	276	248
42	294	---	275	225	270	218	296	263
43	249	---	213	148	155	191	181	186
44	298	---	253	264	171	232	261	247
45	247	---	234	198	193	230	228	222
46	238	---	145	199	223	202	183	198
47	230	---	150	182	219	140	139	177
48	176	---	171	146	169	122	163	158
49	167	---	110	182	---	145	152	151
50 **	200	---	60	146	---	146	153	141
51	95	---	58	89	---	57	89	78
52	176	---	83	134	---	89	252	146
53	165	---	44	104	---	127	162	120
Average	233	---	178	197	222	183	215	204

* First day of bedrest.
** Last day of bedrest.

Table III - Part II

URINARY POTASSIUM (mEq.)

Fourteen Day Bedrest Experiment

A. Bedrest Period

Day	AL	TO	MO	DC	CB	CP	AI	Average
3	56	46	64	53	--	--	--	55
4	76	67	66	81	57	--	--	69
5	49	54	51	59	41	37	--	49
6	54	48	42	46	46	28	--	44
7	73	59	41	77	61	53	--	61
8 *	41	39	54	49	58	49	--	48
9	78	68	86	58	67	79	--	73
10	71	51	53	63	62	57	--	60
11	70	57	86	72	59	73	--	70
12	88	101	89	101	89	64	--	87
13	82	79	83	74	73	61	--	75
14	76	63	87	97	82	86	--	82
15	93	109	102	116	112	100	--	105
16	71	78	72	58	71	57	--	68
17	90	86	91	83	76	87	--	86
18	71	66	57	63	40	69	--	55
19	55	62	70	47	41	57	--	55
20	66	58	61	58	56	48	--	58
21	67	59	61	60	53	58	--	60
22 **	51	51	41	54	55	55	--	51
23	42	57	41	53	45	54	--	49
24	59	39	40	47	51	42	--	46
25	62	47	32	49	52	40	--	41
Average	67	63	64	66	61	60	--	64

* First day of bedrest.
** Last day of bedrest.

Table III - Part II

URINARY POTASSIUM (mEq.)

Fourteen Day Bedrest Experiment

B. Bedrest with Exercise Period

Day	AL	TO	MO	DC	CB	CP	AI	Average
32	54	--	61	79	53	82	--	66
33	47	--	52	59	57	34	47	53
34	66	--	47	63	63	40	63	57
35	28	--	31	38	38	32	75	40
36 *	77	--	84	86	76	68	73	79
37	73	--	89	82	94	80	83	84
38	62	--	84	75	75	72	85	76
39	70	--	97	85	90	77	90	85
40	53	--	99	59	70	69	72	70
41	67	--	98	76	70	68	82	77
42	71	--	90	66	84	84	70	78
43	62	--	95	63	79	68	60	71
44	75	--	94	82	51	81	75	76
45	53	--	77	60	62	102	59	69
46	64	--	48	64	51	74	75	63
47	61	--	56	52	53	65	77	61
48	60	--	63	55	59	68	78	64
49	67	--	52	74	--	69	73	67
50 **	66	--	66	52	--	98	74	71
51	34	--	48	54	--	59	62	51
52	75	--	52	65	--	34	68	59
53	41	--	26	51	--	47	69	47
Average	60	--	69	65	66	68	72	67

* First day of bedrest.
** Last day of bedrest.

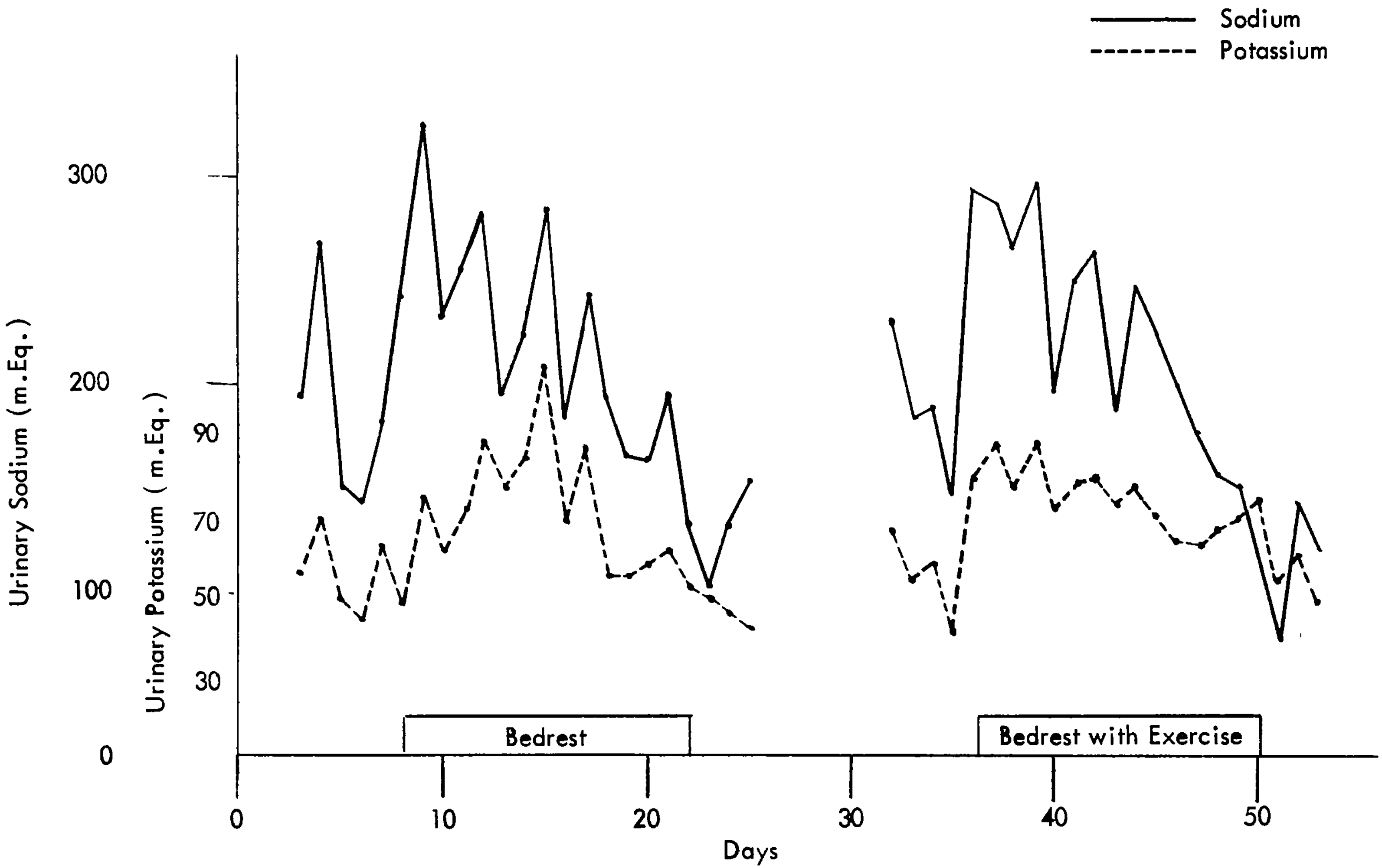

Figure 3. Average daily 24-hour urinary sodium and potassium.

Table IV

TWENTY-FOUR HOUR URINARY SODIUM-POTASSIUM RATIO

Fourteen Day Bedrest Experiment

A. Bedrest Period

Day	AL	TO	MO	DC	CB	CP	AI	Average
3	2.69	4.26	3.07	4.13	---	---	---	3.53
4	2.69	4.38	3.80	3.58	5.47	---	---	3.98
5	2.32	3.72	2.37	2.94	3.82	4.27	---	3.24
6	2.98	2.20	2.76	4.47	2.82	4.67	---	3.31
7	3.73	2.64	2.82	2.25	3.37	3.37	---	3.03
8 *	3.80	5.02	5.38	4.73	5.62	5.32	---	4.97
9	4.16	4.66	4.44	4.22	5.40	4.17	---	4.50
10	3.71	6.50	3.61	3.88	4.33	3.91	---	4.32
11	3.41	4.80	3.44	3.41	4.61	3.12	---	3.79
12	3.40	3.25	2.93	2.74	3.58	3.10	---	3.16
13	3.17	1.97	2.28	2.39	2.47	2.98	---	2.54
14	3.38	3.28	2.35	2.55	2.53	2.62	---	2.78
15	2.66	3.07	2.52	2.82	2.13	3.10	---	2.71
16	3.07	2.28	2.63	3.68	2.38	2.24	---	2.71
17	2.63	3.07	3.16	3.06	3.05	2.05	---	2.83
18	2.85	3.28	3.45	3.57	2.97	2.98	---	3.18
19	3.07	2.87	2.14	4.08	3.82	2.71	---	3.11
20	3.00	2.60	2.18	3.17	3.21	2.91	---	2.84
21	3.08	3.18	2.93	3.31	4.54	2.79	---	3.30
22 **	3.72	3.07	1.97	2.05	2.40	2.41	---	2.60
23	2.21	1.82	2.60	2.15	2.35	1.64	---	2.12
24	2.89	2.92	2.0	2.46	4.64	2.50	---	2.90
25	3.09	2.42	3.31	3.63	4.48	2.55	---	3.24
Average	3.11	3.35	2.96	3.27	3.63	3.11	---	3.23

* First day of bedrest.
** Last day of bedrest.

Table IV

TWENTY-FOUR HOUR URINARY SODIUM-POTASSIUM RATIO

Fourteen Day Bedrest Experiment

B. Bedrest with Exercise Period

Day	AL	TO	MO	DC	CB	CP	AI	Average
32	4.57	---	3.06	3.00	5.39	2.41	---	3.68
33	3.72	---	3.59	2.28	3.26	2.90	5.25	3.50
34	3.53	---	2.89	2.88	3.71	3.30	3.12	3.24
35	5.75	---	2.80	4.21	3.84	3.00	3.16	3.79
36 *	4.64	---	3.85	4.01	3.71	---	2.17	3.67
37	3.78	---	2.95	3.07	2.98	3.52	4.30	3.43
38	4.38	---	2.95	4.20	3.36	3.16	3.29	3.55
39	5.32	---	2.60	3.23	2.88	4.12	3.35	3.58
40	4.09	---	2.06	2.89	2.20	3.20	3.06	2.91
41	4.52	---	2.44	3.28	2.81	3.20	3.36	3.26
42	4.14	---	3.05	3.40	3.21	2.59	4.22	3.43
43	4.01	---	2.24	2.34	1.96	2.80	3.01	2.72
44	3.97	---	2.69	3.21	3.35	2.86	3.48	3.26
45	4.66	---	3.03	3.30	3.11	2.25	3.86	3.36
46	3.71	---	3.02	3.10	4.37	2.72	2.44	3.22
47	3.77	---	2.67	3.50	4.13	2.15	1.80	3.00
48	2.93	---	2.71	2.65	2.86	1.79	2.08	2.50
49	2.49	---	2.11	2.45	---	2.10	2.08	2.24
50 **	3.03	---	.90	2.80	---	1.48	2.06	2.05
51	2.79	---	1.20	1.64	---	.96	1.43	1.60
52	2.34	---	1.59	2.06	---	2.61	3.70	2.46
53	4.02	---	1.69	2.03	---	2.70	2.34	2.55
Average	3.91	---	2.54	2.97	3.36	2.66	3.02	3.07

* First day of bedrest.

** Last day of bedrest.

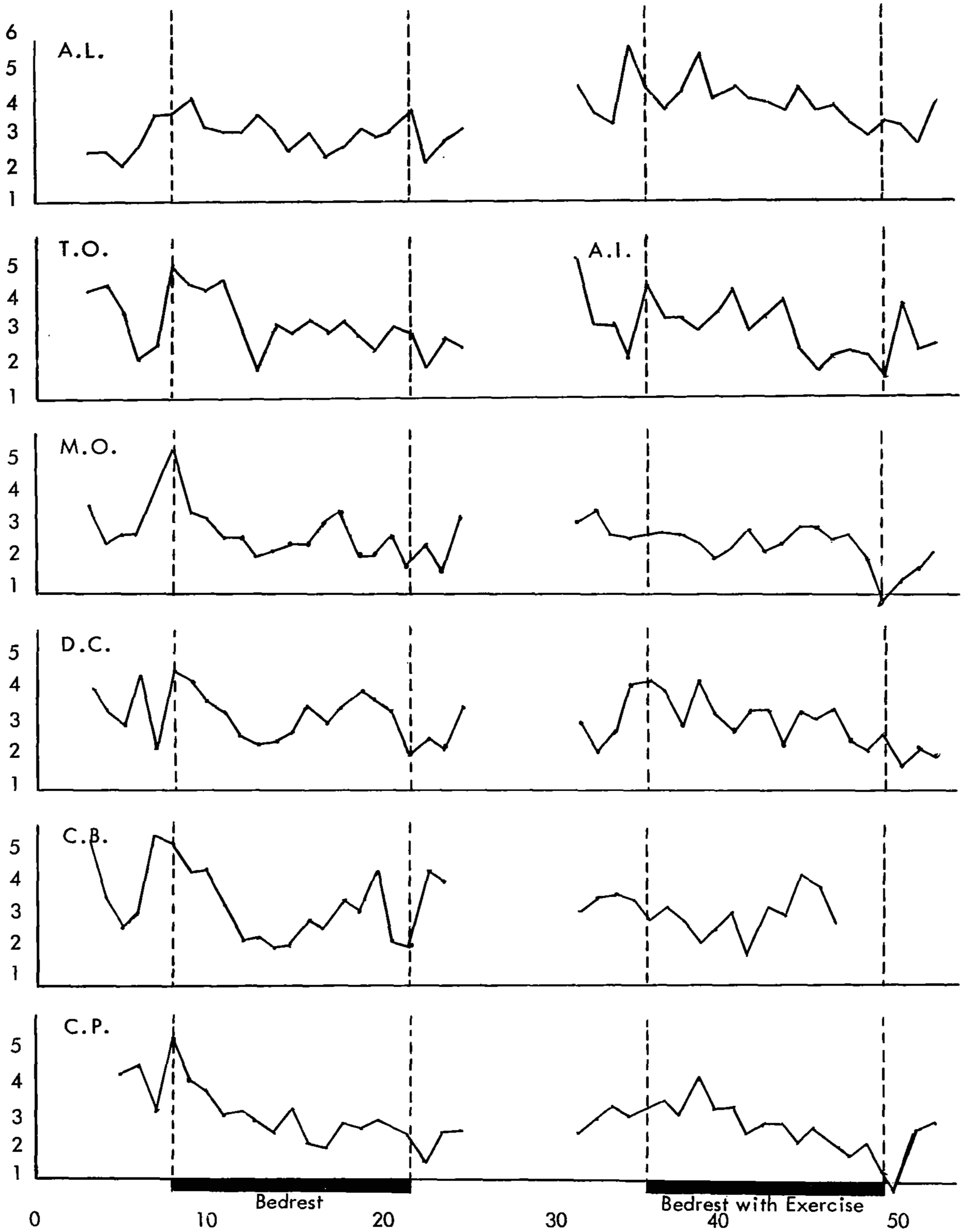

Figure 4. Twenty-four-hour urinary sodium potassium ratios.

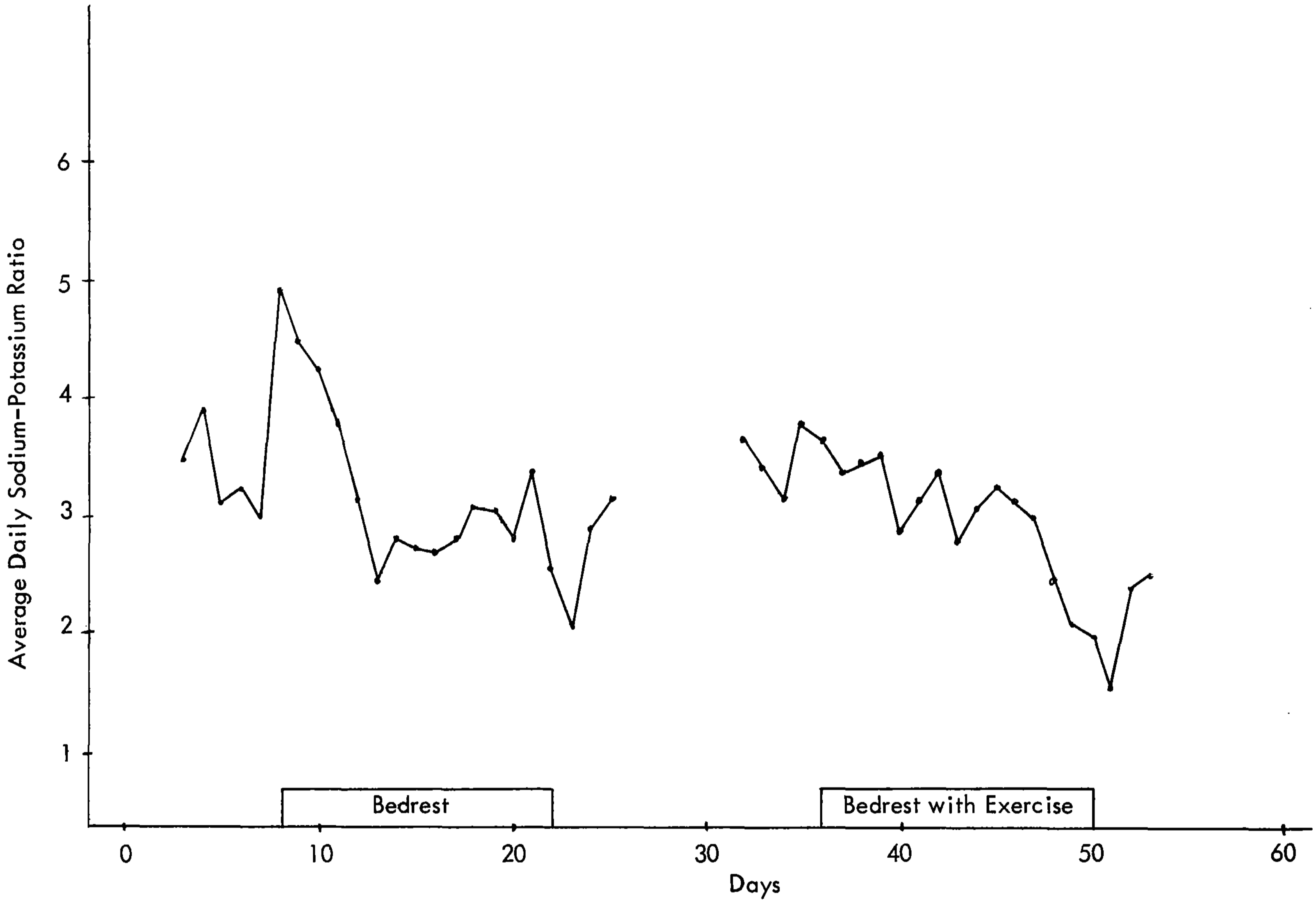

Figure 5. Average daily sodium-potassium ratio on six subjects.

excretion after termination of the periods of recumbency. The pattern of average daily potassium excretion during the first period shows an upward trend in the excretion for the first week of recumbency and a downward trend for the second week. The average daily potassium excretion follows a pattern similar to that of sodium in the bedrest plus exercise period.

A more detailed analysis of these data is in progress and will be presented at a time when the analysis is complete. Several observations can be made at this time which are of interest. The 7 a.m. - 7 p.m./7 p.m. - 7 a.m. ratios (day-night ratio) for urine sodium and urine volume follow the same pattern, with an average ratio of 1.40 for sodium and 1.34 for urine volume during the first study period. A ratio of 1.34 for day-night urine sodium and 1.29 for day-night urine volume was found for the second period. The day-night ratio for excretion of potassium was 1.87 for the first period and 1.99 for the second period. Inspection of the plots for individual subjects showed this very distinct difference in day-night excretion of potassium which was more pronounced than the day-night difference for urinary volume.

The urinary sodium to potassium ratios showed a similar pattern of change in all subjects. There was a trend downward over the first week of recumbency. Some subjects then showed a trend upward in the ratio. This change in the ratio appears to be more a reflection of a decreased sodium excretion rather than an increased potassium excretion.

The potassium excretion followed a more variable pattern in the individual subjects. There was an increased excretion of urinary potassium during recumbency. In some cases this increased excretion appeared to follow the increased urinary volume output, but this was not always the case. The data do not suggest any inverse relation between the urinary excretion of sodium and potassium.

The results of the RISA blood volume are presented in Table V. Figure 6 shows a plot of the daily averages of blood volume for the six subjects throughout the experiment. The blood volume of individuals showed considerable variation from day to day. Changes from the average blood volume for a given subject range from as great as 23 percent below his average for the study period to as much as 49 percent above the average value. The variation in daily averages for the six subjects was not as great, with values of 15 percent below the average and 9 percent above the average values.

The average blood volume during the second study period (including pre-bedrest and post-bedrest phases) was less for all subjects, with an average decrease of 0.7 liter. However, the variation in the blood volume from the average for a given subject during the second period (including pre-bedrest and post-bedrest phases) showed a range from 23 percent below his average for the study period on one subject, to 19 percent above the average for another. The variation in the daily average of blood volume for all six subjects ranged from 7.8 percent

Table V

RISA SPACE VOLUME
(liters)

Fourteen Day Bedrest Experiment

A. Bedrest Period

Day	Subjects AL	TO	MO	DC	CP	CB	AI	Average
3	---	5.3	6.4	4.8	5.4	5.8	---	5.5
5	5.6	5.4	---	---	---	---	---	5.5
8 *	6.5	6.1	6.7	5.4	6.4	6.1	---	6.2
9	6.4	5.5	7.4	5.3	6.4	6.0	---	6.2
10	5.3	5.0	6.0	4.4	4.4	4.6	---	4.9
11	5.5	6.3	---	---	---	---	---	6.0
16	5.1	6.9	7.9	7.9	4.4	5.7	---	6.3
18	5.7	5.0	5.8	4.3	6.2	7.0	---	5.7
22 **	6.3	5.8	---	5.4	5.9	7.0	---	6.1
26	6.0	5.6	5.8	4.7	5.3	5.7	---	5.5
Average	5.8	5.7	6.6	5.3	5.6	6.0	---	5.8

B. Bedrest with Exercise Period

Day	AL	TO	MO	DC	CP	CB	AI	Average
33	5.5	---	5.8	5.2	5.0	4.1	3.7	4.9
36 *	5.5	---	5.9	5.2	6.4	5.9	4.9	5.7
37	5.0	---	5.8	5.0	5.6	4.9	4.2	5.1
40	5.1	---	6.2	5.4	5.7	6.2	4.4	5.5
44	5.2	---	5.8	4.1	5.0	4.3	4.9	5.0
50 **	4.3	---	5.1	4.5	4.9	4.0	4.1	4.7
53	4.0	---	5.6	5.2	---	---	4.1	4.7
Average	4.9	---	5.7	4.9	5.4	5.2	4.3	5.1

* First day of bedrest.

** Last day of bedrest.

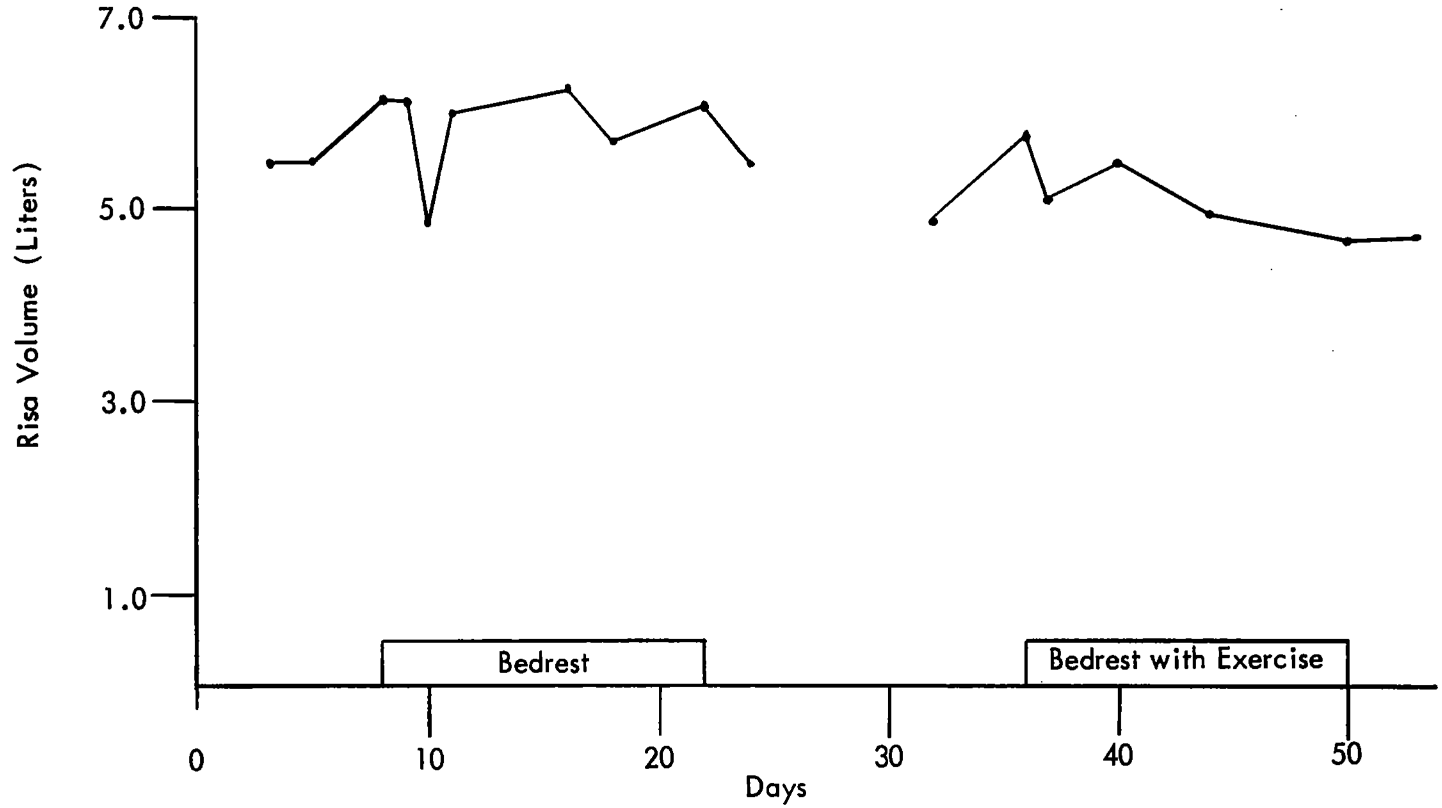

Figure 6. Average RISA volumes.

above the average for this period. There appeared to be a progressive downward trend of the blood volume during the second period of bedrest.

The weight changes during the bedrest study were +0.3, -0.5, +0.1, +0.1, -0.5, and +1.0 kilograms. The weight changes during the bedrest with exercise study period were +1.8, -1.1, -1.4, -1.2, -0.4, and -0.4 kilograms. There was no apparent correlation of this weight change with blood volume, tolerance to passive tilt, or urinary volume output.

DISCUSSION

The results of this study confirm the previous observation of diuresis with bedrest. Deitrick, Whedon, and Shorr[10] observed a 250 cc. increase in daily volume of urine during bedrest. Birkhead et al.[13] found a similar diuresis with prolonged bedrest. Diuresis also is found to occur with water immersion[6,7,14,15,16,17,18,19] and apparently at an accelerated rate compared to bedrest. A detailed discussion of this is presented elsewhere.[20]

Decreased insensible losses and shifts of fluids from extravascular compartments both likely contribute to this increased urine volume in the recumbent position. The mechanism by which this occurred (i.e., through volume receptors, ADH inhibition, increased renal blood flow, etc.) cannot be ascertained from the data available in this study.

The subjects in this study drank water ad libitum, and showed a decreased intake of fluid during bedrest. If they were required to continue consuming the same fluid intake during bedrest as before, it is likely that the urine volume would have been proportionately greater. Measurements of body weight do not aid interpretation of fluid balance since the total metabolic status of the subject is unknown.

The complexity of the fluid-electrolyte control and excretion mechanisms prevents accurate interpretation of the findings of this study. Most reports on the effect of posture on electrolyte excretion have been obtained through short-term studies. Numerous observations[21,22,23,24] are available and several mechanisms are proposed in the literature to explain the changes which occur.

The finding of an increase in both sodium and potassium excretion in the urine with bedrest suggests that a shift of fluid and diffusible electrolytes from the extravascular compartments may account for the findings. Berliner[25] has described that increased excretion of potassium accompanies an increased excretion of sodium under many conditions.

The observation of a decrease in urinary sodium-potassium ratio as bedrest progresses suggests the possibility of a secondary aldosterone effect. However, this decreased ratio could have been accounted for by a trend downward in the sodium excretion alone. The complexity of the relationship of sodium excretion, potassium excretion, and urine volume prevents incrimination of a single mechanism as the reason for the findings in this study. Aldosterone has been found to increase[21] upon standing for short periods. No information was found in the literature describing aldosterone changes with prolonged bedrest, and aldosterone was not measured in this study.

Observation in the literature of changes in blood volume with prolonged bedrest are limited. Deitrick, Whedon, and Shorr[10] noted in four experimental subjects a decline in plasma volume that ranged from 120 to 320 cc., with an average decrease of 191 cc. at the end of 3 weeks immobilization. During the next 3 to 4 weeks of continued recumbency, the blood volume returned to control levels. Taylor et al.[12] noted a 15 percent decrease in plasma volume after 3 weeks of bedrest. Widdowson[26] described the effect of bedrest on plasma volume as reflected in hemoglobin and hematocrit determinations. He noted a fall in hematocrit (increase in plasma volume) after 1 or 2 hours of recumbency and a return to normal and rise above control levels (decrease in plasma volume) after 4 days of bedrest. He attributed the secondary rise of hematocrit (decrease in plasma volume) to be a result of inactivity rather than recumbency. More information is available[26,27,28,29,30,31,32,33,34,35,36,37] on the effect on blood volume of acute changes in posture.

The large variations in RISA blood volume in the subjects of this study prior to bedrest make it difficult to interpret the changes that occur during bedrest. McCally[9] has described difficulties in interpretation of blood volumes obtained by a RISA technique in water immersion studies.

There was a significant decrease in blood volume in all of the subjects during the second period of bedrest to which an exercise program was added, compared to the first period of bedrest. There also appeared to be a significant trend downward of the RISA blood volume as the second bedrest period (with exercise) progressed. It is not known whether this is related to the exercise performed. Studies reported in the literature on the effect on blood volume have been on short-duration exercise studies, and both increases[38,39] and decreases[40,41,42] have been observed.

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